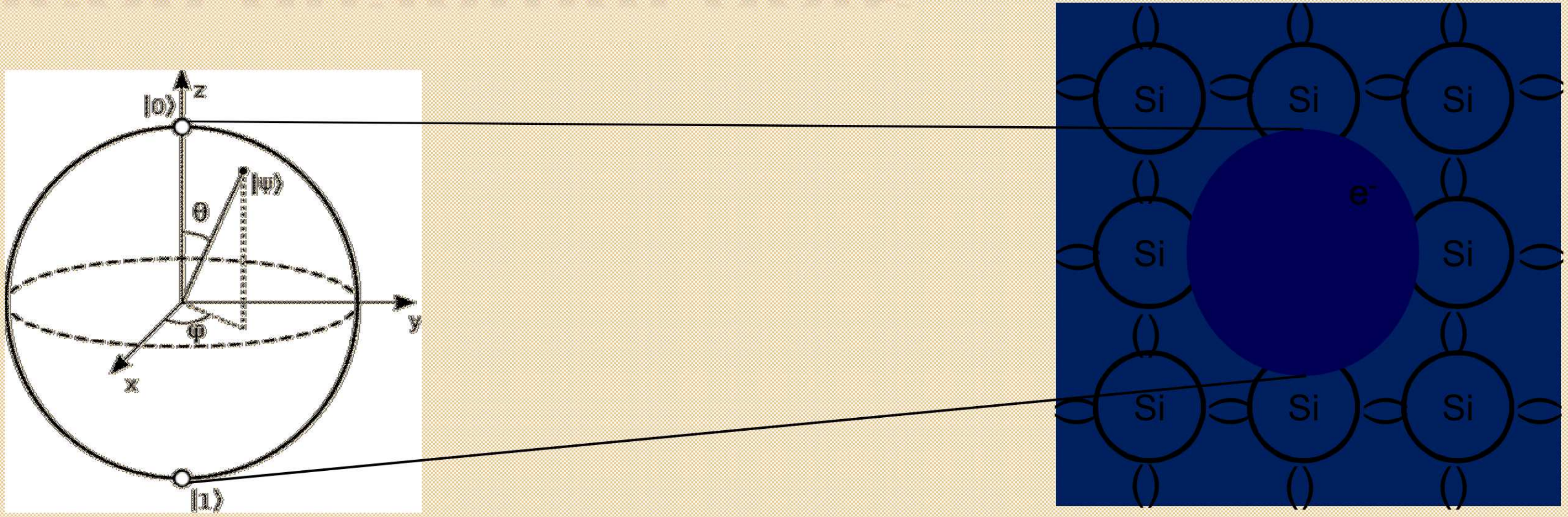
SAND2015-1280PE

Counted Antimony donors in Silicon quantum dots



M. Singh, J. L. Pacheco, D. Perry, E. Garratt, G. Ten Eyck, N. C. Bishop, J. R. Wendt, D. R. Luhman, E. Bielejec, M. S. Carroll and M. P. Lilly

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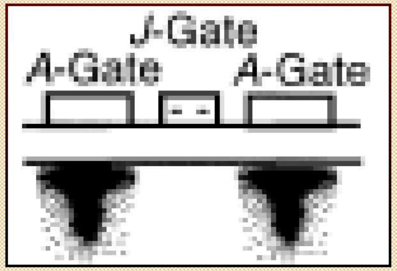
Sandia National Laboratories

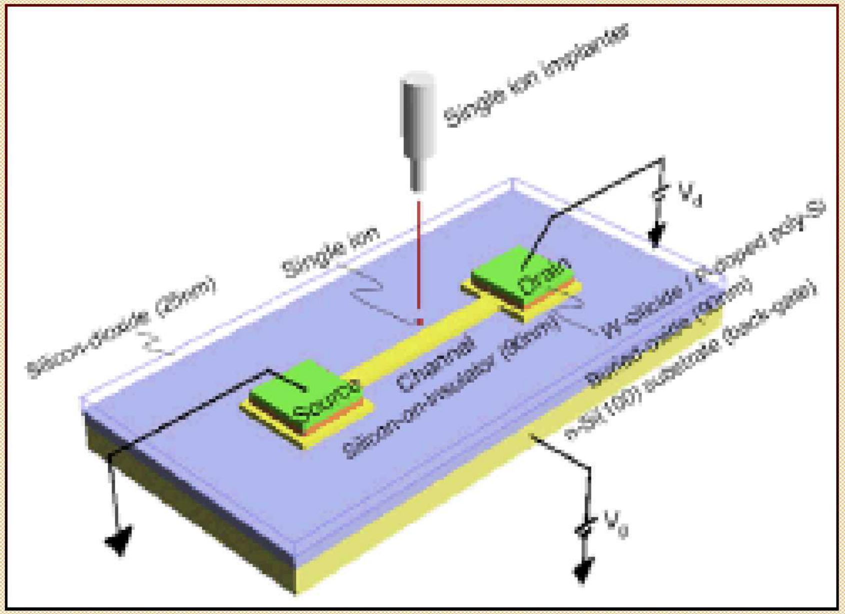
Why count donors?

Two qubit experiments require deterministic control over number of donors

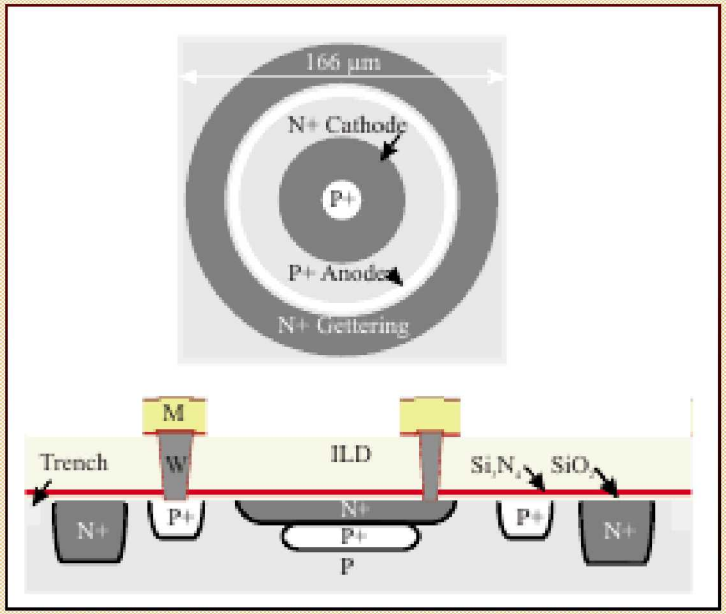


B.E. Kane, Nature **393**, 133 (1998)

How to count donors:

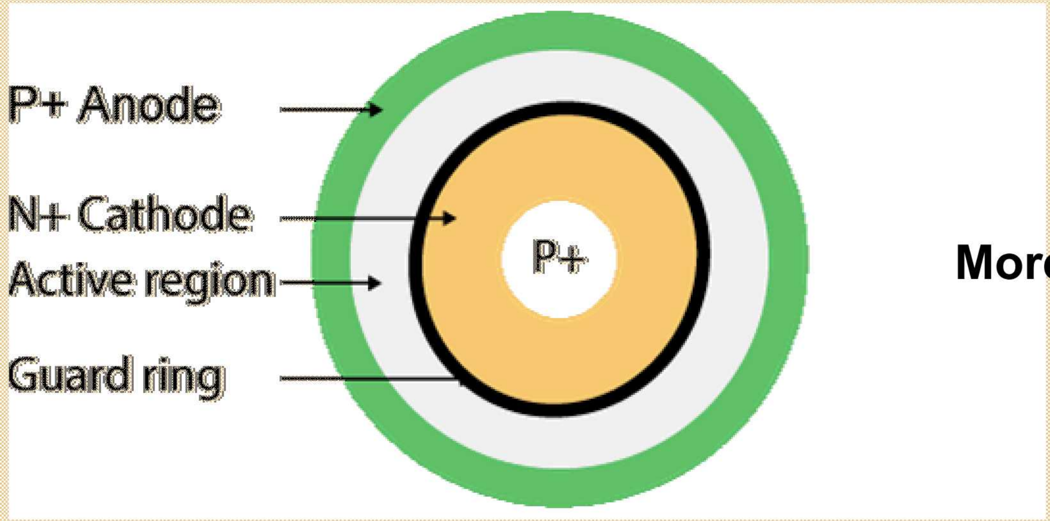


T. Shinada et al., Nanotechnology 19, 345202 (2008)

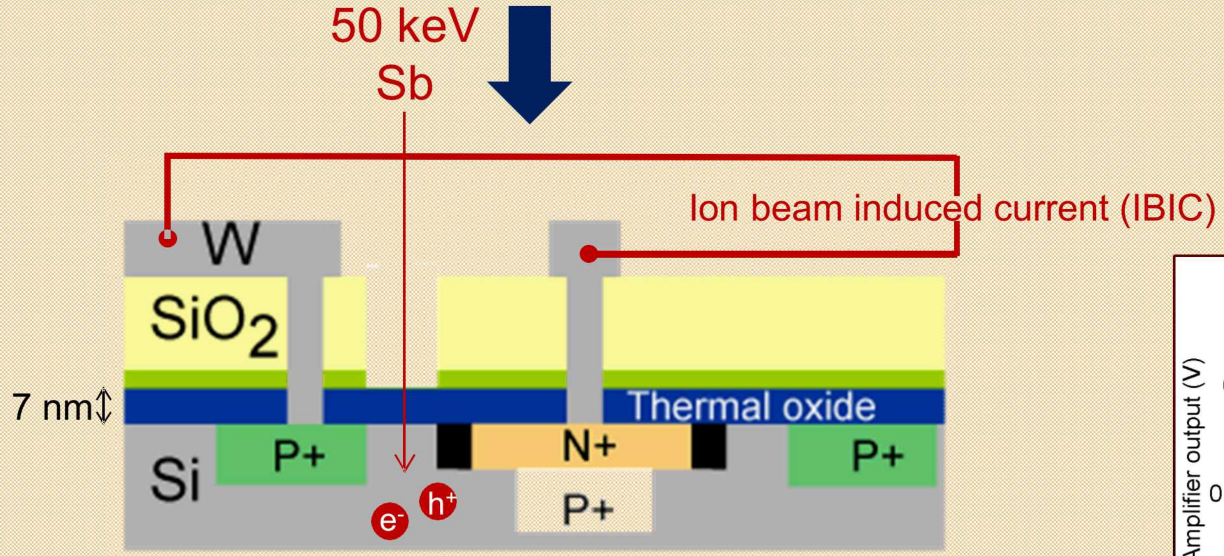


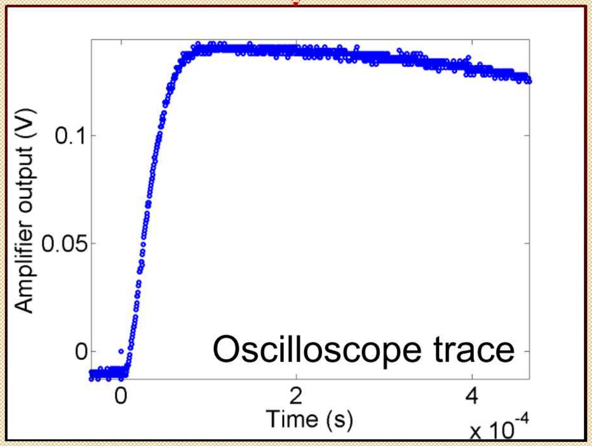
J. A. Seamons et al., APL **93**, 043124 (2008)

How the diode detector works



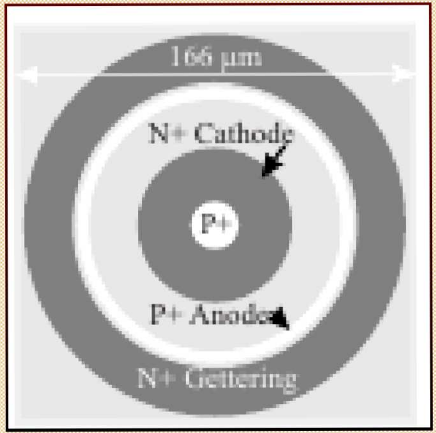
More details: J. Pacheco – S37.00010

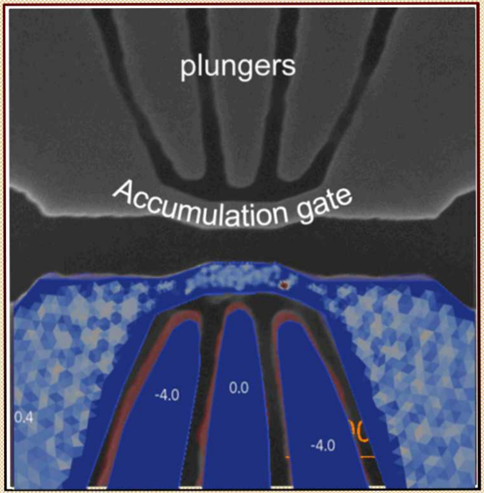


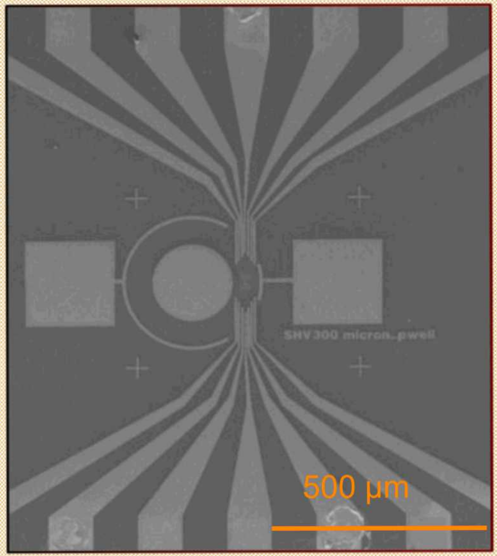


Integration with Single Electron Transistors

Two qubit experiments also require functional SETs







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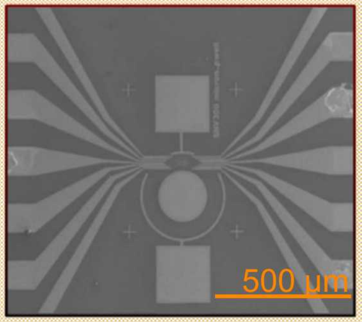
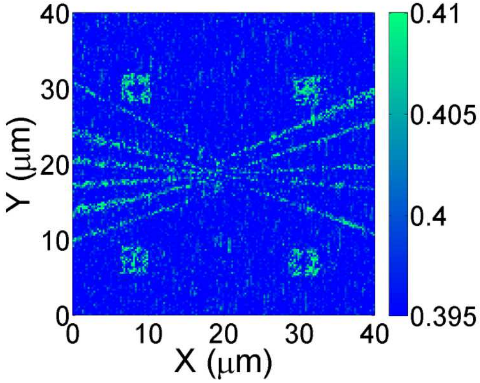
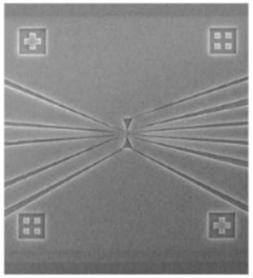
Integration with Single Electron Transistors



Single ion detection

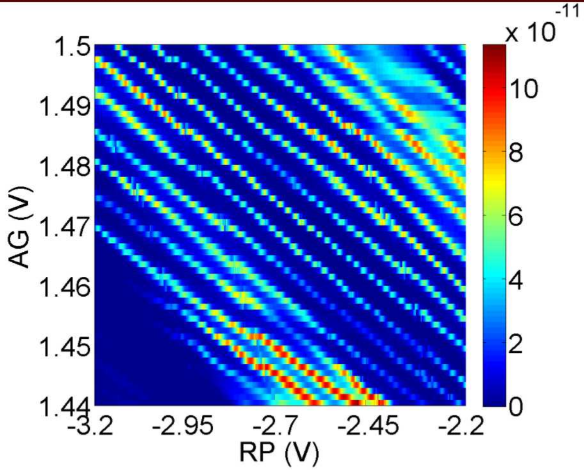




25 um

Ion beam induced current map with 50 keV Sb <1> ion/pulse and SEM image of device

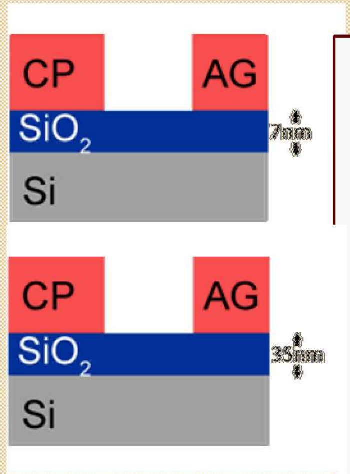
SET with capacitances agree with simulations of an electrostatically defined dot

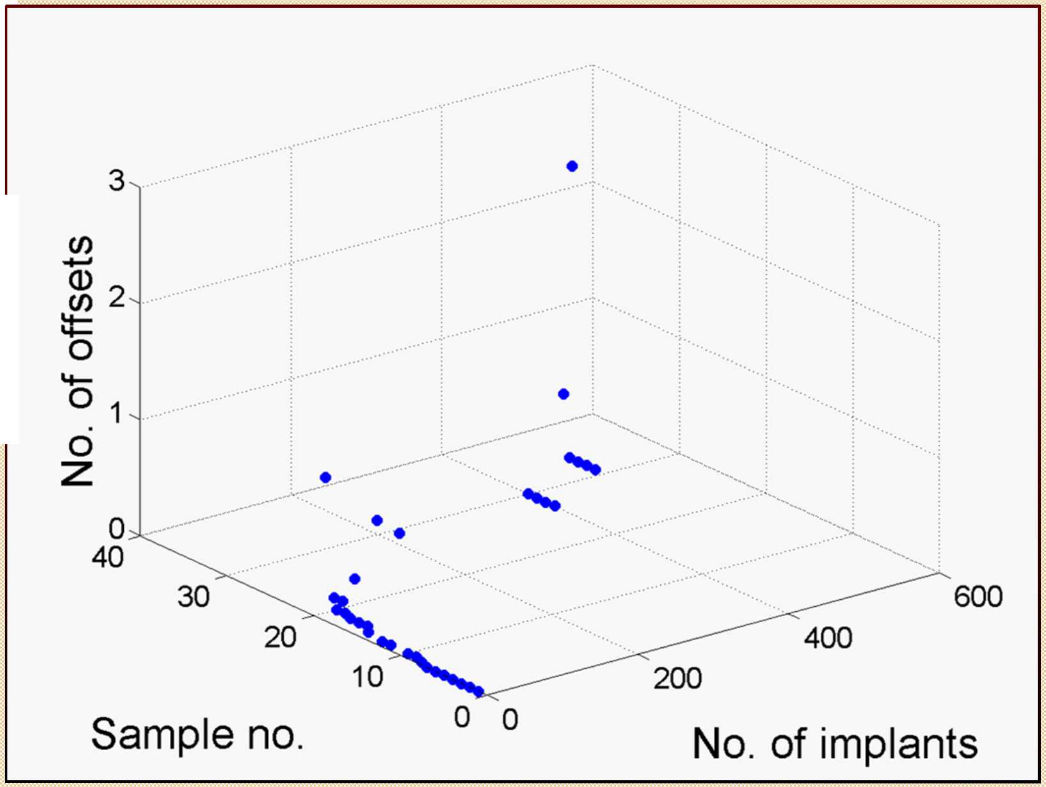


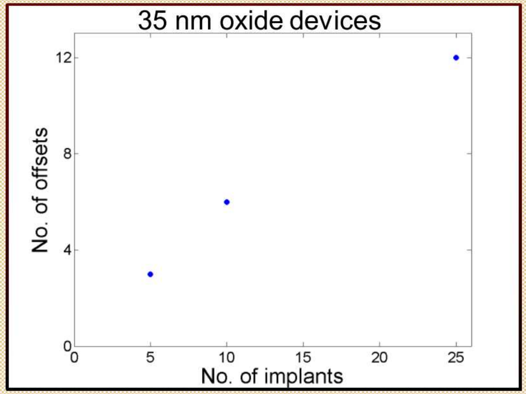
T = 25 mK, C_{AG} = 26.7 aF, C_{RP} = 1.6 aF, C_{CP} = 2.2 aF, C_{LP} = 1.4 aF

Diode detectors that can detect a single ion integrated with functional SETs.

Offsets in 7 nm devices



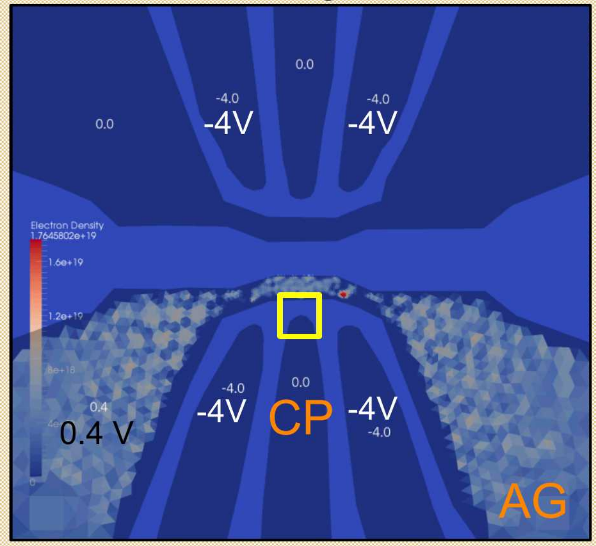


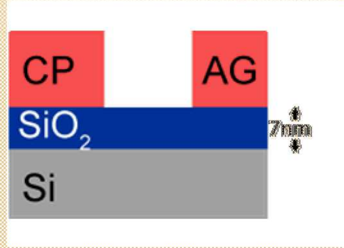


- Number of offsets always very small compared to the of number of implants
- Ruled out possibilities of being at the wrong depth, wrong location, donors not activated etc.
- Exploring geometry considerations with semi-classical simulations

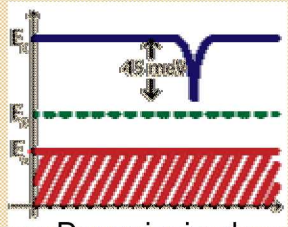
Insight from simulations – 7 nm oxide

Electron density at interface

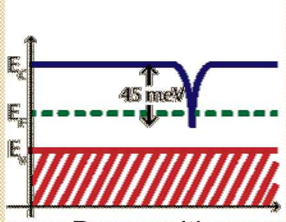




- Threshold of ~ 0.4 V obtained using fixed charge as a free parameter
- Plungers have ‘weak’ effect compared to AG

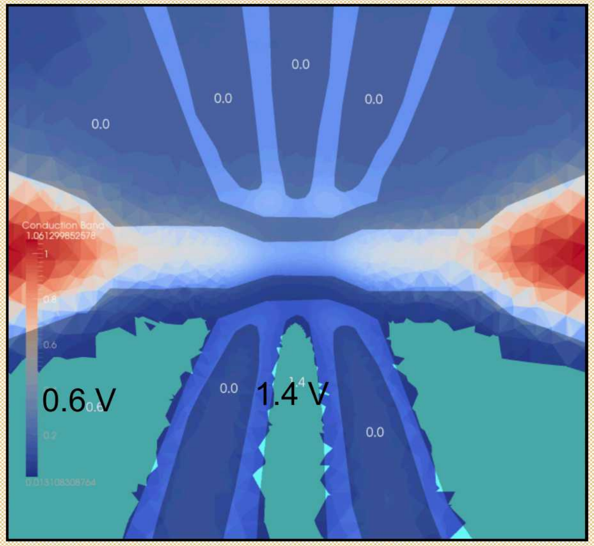


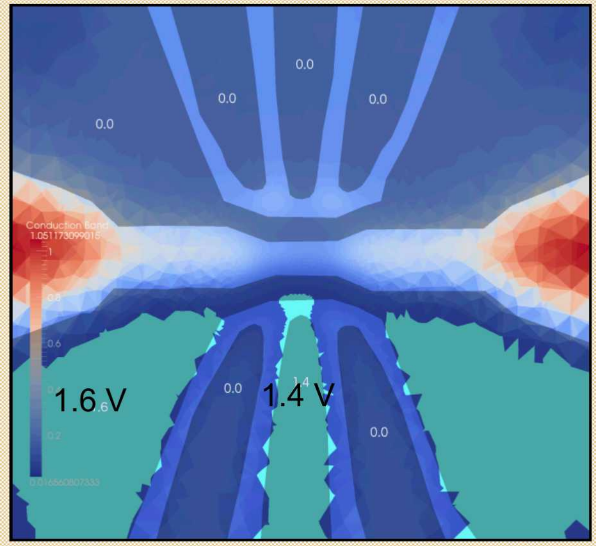
Donor ionized



Donor with e^-

Conduction band 30 nm below Si/SiO_2 interface.



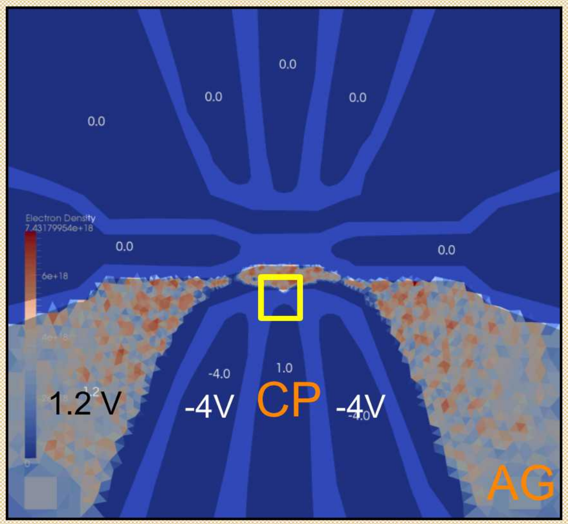


- To change ionization state of donor, AG ~ $4V_{th}$ - making dot formation impossible

Offsets in 7nm oxide samples are difficult to observe

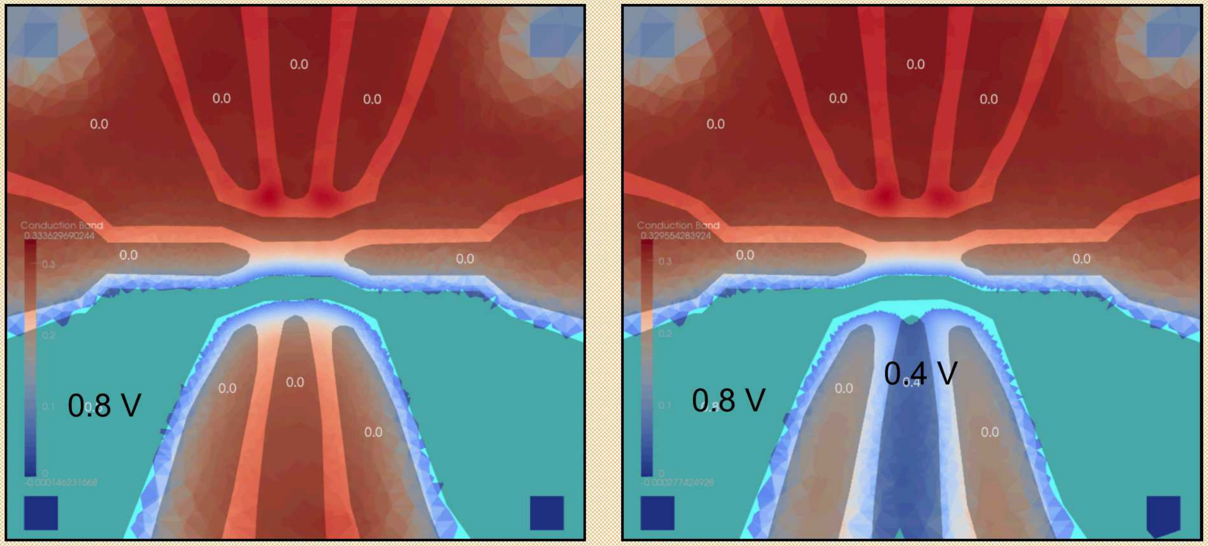
Insight from simulations – 35 nm oxide

Electron density at interface



- Threshold of ~ 0.8 V obtained using fixed charge as a free parameter
- Plungers have stronger coupling than the 7 nm case

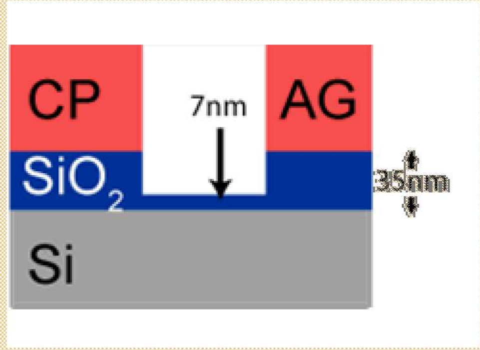
Conduction band 30 nm below Si/SiO_2 interface. Donors in green regions have e⁻

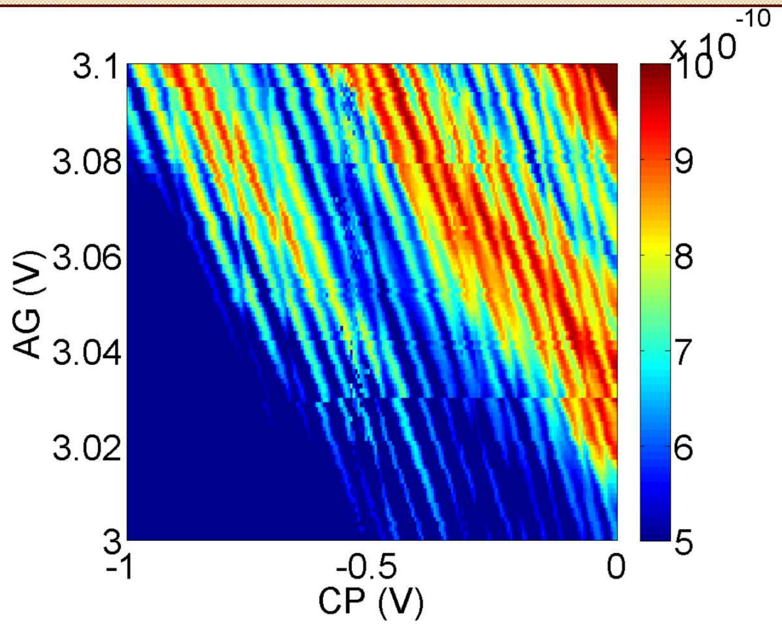


- To change ionization state of donor, a small change on CP is sufficient

Offsets in 35nm oxide samples are easy to observe

Experimental test



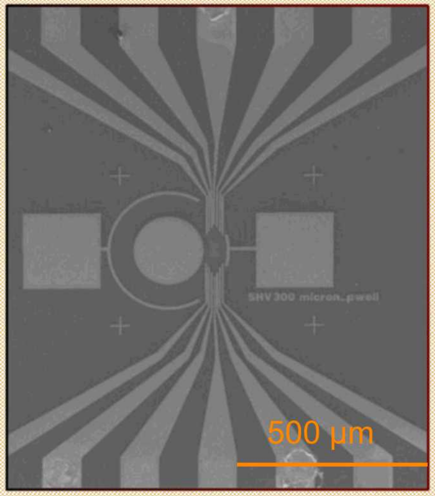


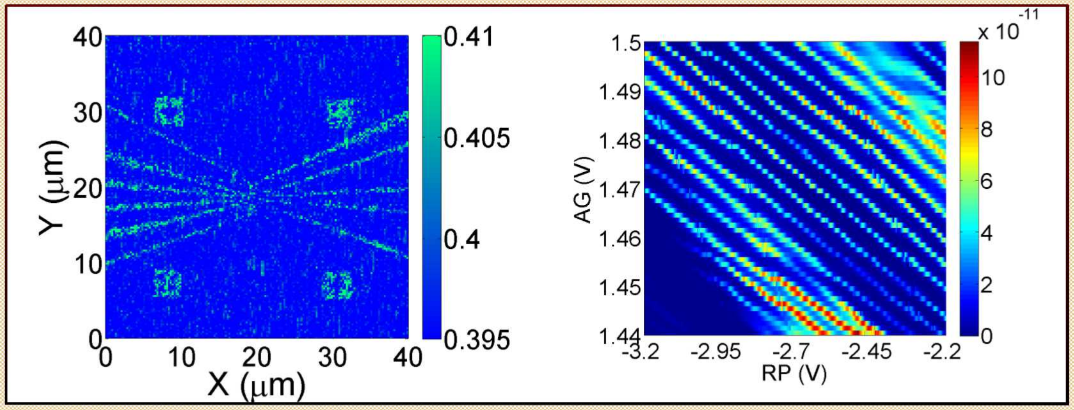
35nm oxide, thinned to 7 nm
25 Sb implants 120 keV ~ 12 offsets

- In samples with 50 timed implants ~ 20 offsets are seen, with 10 implants ~ 6 offsets and with 5 implants ~ 2 offsets are seen
- The geometrical problem indicated by QCAD is the most likely reason for the missing offsets
- New devices with optimal geometry taken into consideration have been fabricated

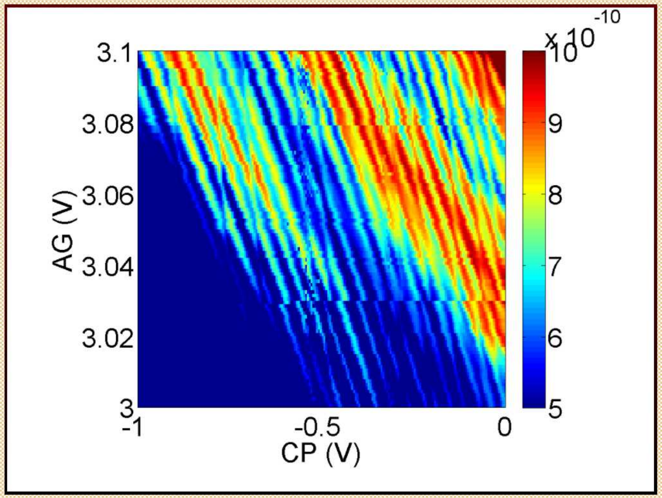
Results

1. Samples with functional SETs integrated with single ion detectors are fabricated





2. Functional geometry for observing offsets is predicted and tested

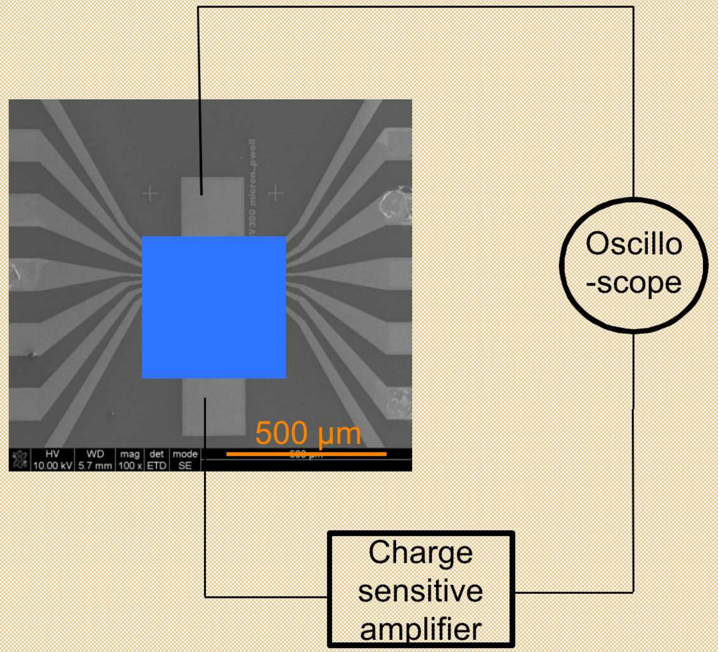


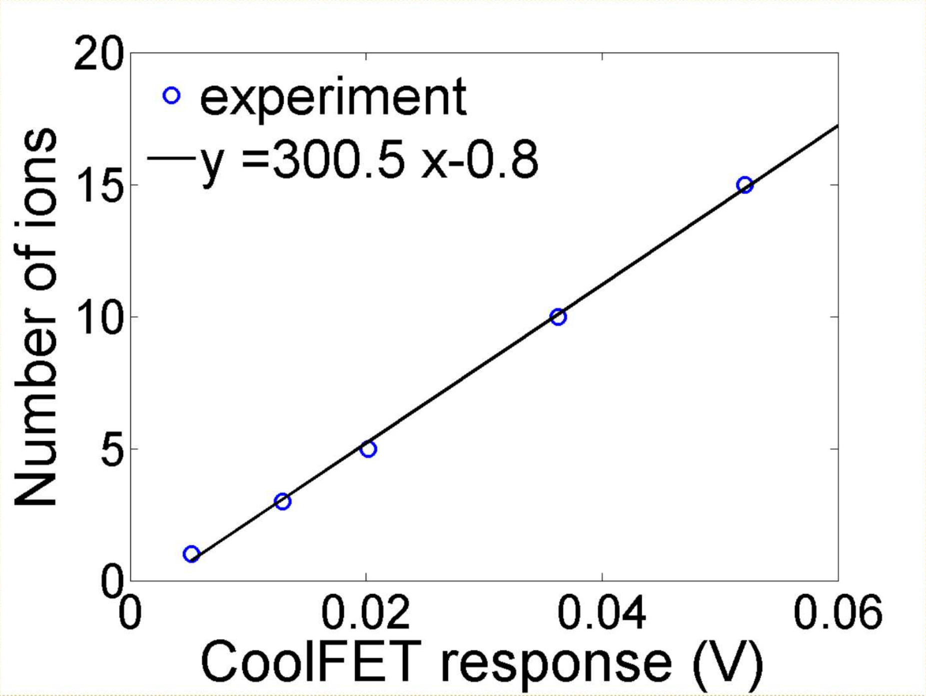
Thank you

Additional Information

Calibration and counting

Counting the ion implants





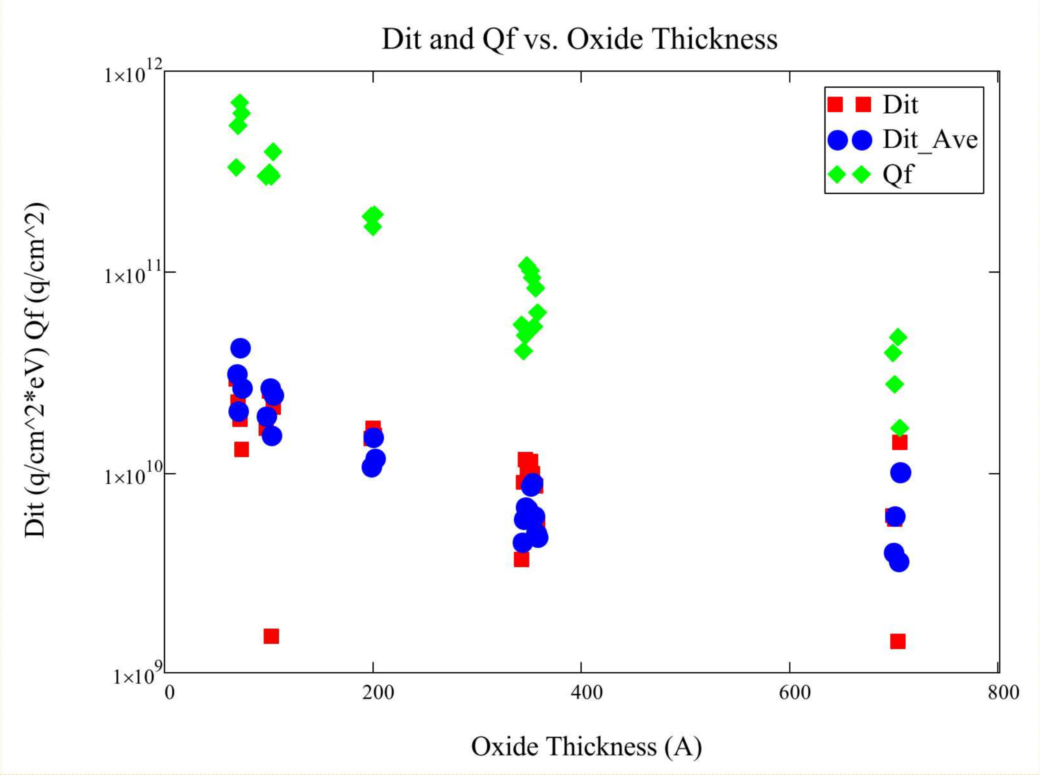
- With this detection capability, the number of ions being implanted can be counted

Sample Synthesis: 7 nm oxide

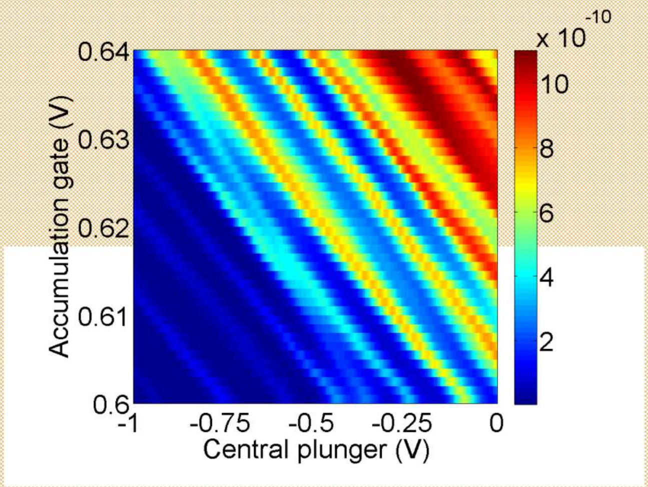
1. Interface trapped charge (D_{it}) and fixed charge (Q_f) are concerns for dots and donors near the SiO_2/Si interface

2. Thinner oxides lead to higher fixed charge

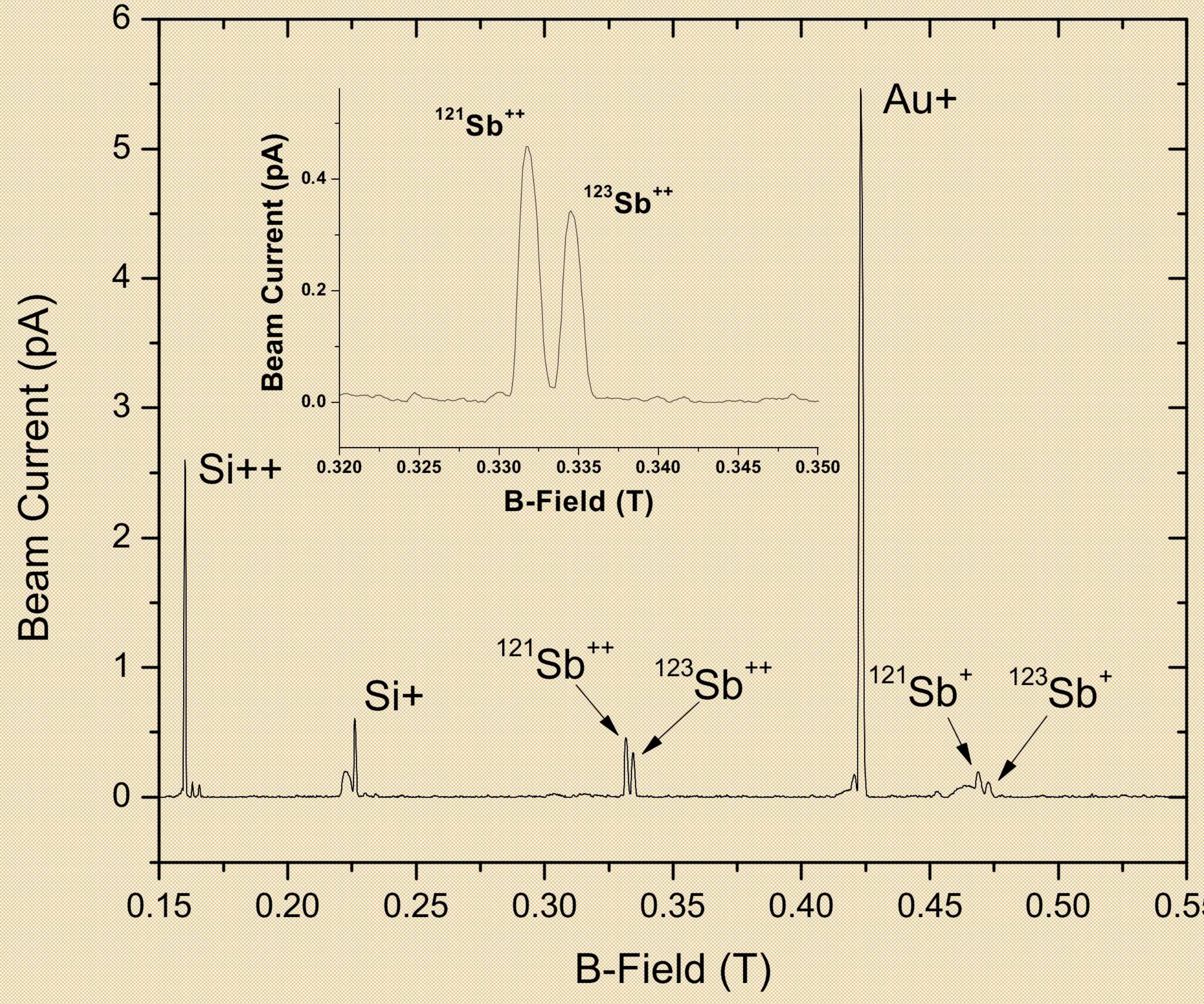
We require deterministic control over:
1. Placement of donors: needs thin oxide
2. Number of donors

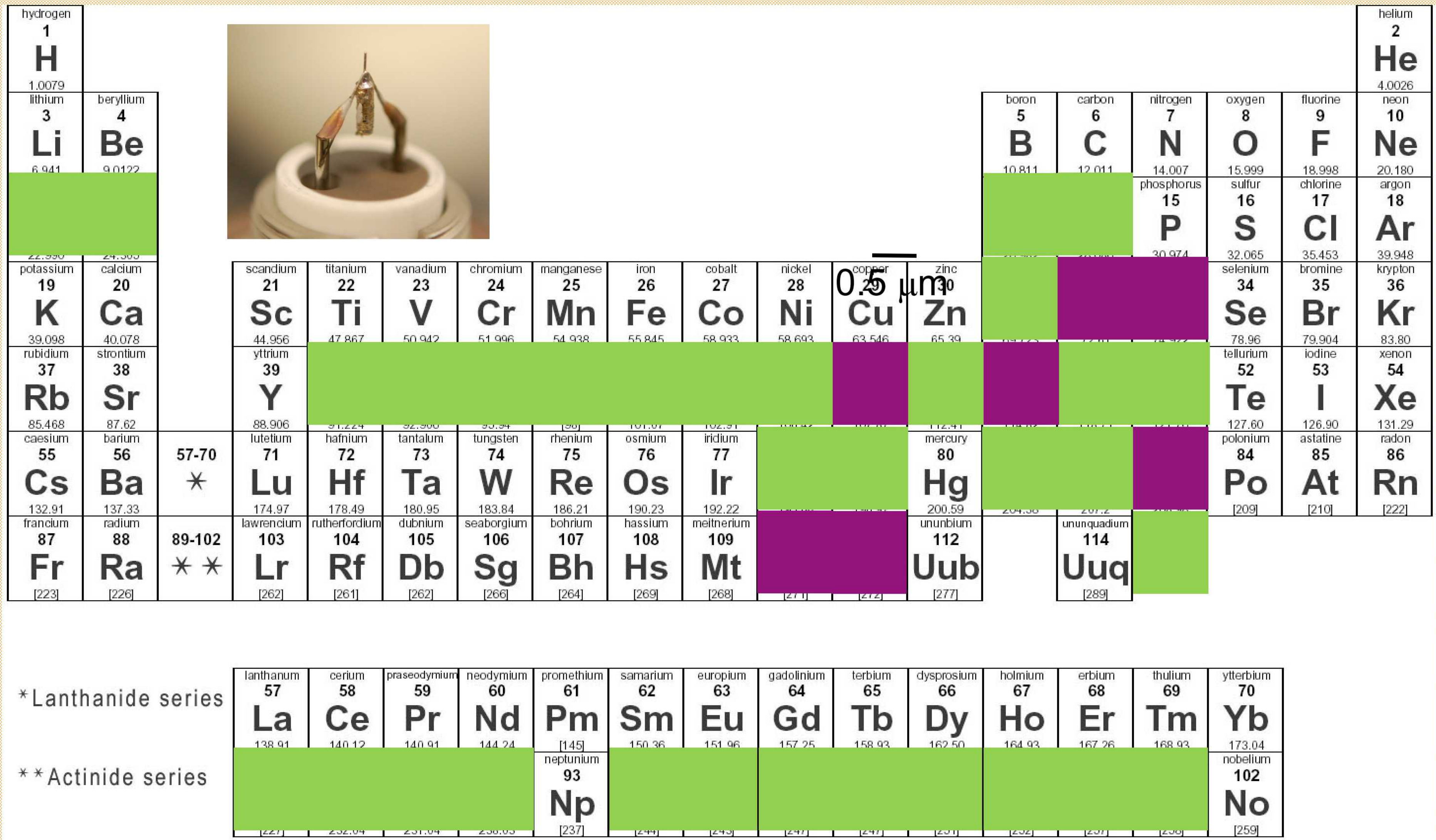


However, we are able to obtain stable single dots in these systems



AuSiSb Mass Spectrum





Capable of Generating Ion Beams from~$^{1}/_{3}$ of the Periodic Table